Achieving Optimal Safety Inventory Levels for Oil Companies using the CONWIP Approach

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***Abstract*— Oil Companies are faced with many operational challenges as it relates to key process functions within their selected manufacturing strategy. These challenges include: high safety stock levels, long lead times, inefficient floor utilization and production planning in regards to bulk/pack raw material receipt, blending, and packaging. The goal of this research study is to address the challenge of high safety stock levels of lubricant products manufactured by oil companies, and to conduct a value stream map (VSM) exercise to frame near term and future state opportunities to optimize cost structures and operational excellence parameters. Based on the analysis of the current VSM for a specified oil company from a lean supply chain perspective, we apply the CONWIP (CONstant Work In Progress) approach to optimize the safety inventory levels, which successfully decreases the costs associated with both raw material and finished goods inventory. In particular, a 3.1 million dollar reduction in finished goods inventory and a 1.4 million dollar reduction in raw material inventory were achieved for a large oil company through implementation of the CONWIP approach. The results of this study indicate this pull-oriented production and inventory control system can certainly benefit additional oil manufacturing companies and help them achieve significant safety inventory cost savings.**

***Keywords*—** *Inventory, CONWIP, Kanban, Oil Industry*

1. Introduction

Manufacturing plants in different industries, all around the world strive to improve their manufacturing operations, to gain and maintain competitive advantages through product quality, waste and cost management and most importantly, being able to respond to changes in customer demand. Traditional production systems often experience excess inventory, higher WIP levels, and longer lead time from order to delivery time. Just-in-time production responds better to changing customer demands, because it ensures producing the right products at the right time and in the right quantity. To achieve this, engineers in different manufacturing facilities are trying to achieve a lean manufacturing system, which is a systematic method for eliminating waste. A lean manufacturing system is one that meets high throughput or service demands with a very low level of inventory.

Different approaches have been implemented in different manufacturing industries to control the lean manufacturing systems. This research will focus on the Kanban and CONWIP approaches, both of which have been studied and implemented separately and also in a hybrid way. The Kanban control uses the levels of buffer inventories in the system to regulate production. When a buffer reaches its preset maximum level, the upstream machine is told to stop producing that part type. The Kanban control ensures that parts are not made except in response to demand.

CONWIP stands for Constant Work-In-Process, and designates a control strategy that limits the total number of parts allowed into the system at the same time. Once the parts are released, they are processed as quickly as possible until they wind up in the last buffer as finished goods. The CONWIP system is different from Kanban in some ways, even though they are both identified as a "pull" system and respond to actual demand. But unlike Kanban, any part released to the system will move to finished goods, leaving all buffers in the system empty. New parts will not be released if the finished goods buffer is full.

Several studies have researched the implementation of the Kanban and CONWIP systems in different manufacturing settings and have identified some of the advantages, including reduction in product flow time, reduction in Work-

International Journal of Supply Chain Management
IJSCM, ISSN: 2050-7399 (Online), 2051-3771 (Print)

In-Progress (WIP), improvement in the on-time delivery, reduction in lead-time, reduction in inventory levels, improvement in inventory turns, waste reduction, etc. This research study uses the replenishment pull systems of Kanban and CONWIP to reduce the WIP of finished goods in a lubricant manufacturing facility.

The remainder of this paper is organized as follows. Section 2 reviews the literature in the area of pull production system with a focus on Kanban and CONWIP systems and identifies the research gap in this field. In Section 3, we describe the Kanban and CONWIP approaches used in this case study. In Section 4, we present the details and results of applying Kanban and CONWIP methods to reduce the WIP of finished goods in a lubricant manufacturing facility. Finally, we conclude the paper in Section 5.

2. Literature Review

Effective production control systems are those that produce the right parts, at the right time, at a low cost. These systems are often referred to as just-in-time (JIT) and Kanban or zero inventory (ZI), which have reduced both inventory levels and lead time in different industries. In this paper we introduce the use of Kanban and CONWIP as a production control tool to ensure shorter flow time and to reduce inventory levels in a refinery.

2.1 Kanban v.s. CONWIP

Ref. [1] described a different type of pull production systems utilized in plants. Through their analysis of both Kanban and CONWIP in relation to production rate, it was shown that the use of cards was pertinent to the proper utilization of the Kanban system. This paper also showed that the Kanban system was more flexible and incurred a lower production rate than the CONWIP system. Ref. [2] explained that in repetitive production systems, the Kanban systems were used to reduce the inventory and lead time. They introduced a modified Kanban system and compared it to a generic Kanban system, and their analysis determined that the generic system was more flexible and that it functioned better at locations where bottlenecks had formed. Ref [3] noted the CONWIP for its ability to handle the supply chains with multiple assembly phases and inconsistent lead times. Historically CONWIP has been defined as a combination of the push and pull systems and has been considered a more efficient means to fully utilize equipment in plants. Ref. [4] suggested a simple production control method for setting the WIP levels to meet target production rates while operating under CONWIP. Using the statistical throughput control on the real-time data, they adjusted the WIP levels while facing undetermined levels of throughput. Ref. [5] presented a simulation that consisted of several production facilities linked with random operation times. Due to random operation times, the downstream machines often lagged behind the upstream machines, which negatively affected storage availability. Through these various tests the authors determined that Kanban had a lower utilization rate and presented more storage availability than CONWIP, and that both processes could only control the maximum WIP. The authors finally concluded that CONWIP is the preferred process despite lack of guidance in the installation process.

2.2 Minimizing Inventory in the Oil Industry

Ref. [6] discussed issues faced by oil companies when managing inventory from different sources. The authors proposed a mixed-integer programming model and a branch and bound method to solve the crude oil unloading problem. Ref. [7] focused on the operations conducted at distribution centers. A mixed-integer linear programming approach was used to model the pipeline scheduling and supply management where production, transportation, inventory management, and client satisfaction were considered simultaneously in the objectives. Ref. [8] developed an optimization model to integrate a production system with a utility system in a refinery in order to minimize the inventory and maximize the total profit. The integrated model was then decomposed into a mixed-integer linear programming model and a nonlinear programming model. A sequential method was designed to solve the two models. Ref. [9] considered a simple approach in the oil transferring process from tanks and the charging schedule for each oil mixture in crude oil inventory management. They proposed an algorithm incorporating uncertainty and availability of the crude oil to solve two mixed-integer linear programming models and a nonlinear model. Ref. [10] stated that the production efficiency decline could affect oil companies. The project development cycle time must be reexamined to eliminate the non-value added activities (about 50% of all activities) within the oil industry. A centralized manner, as opposed to each individual project, was recommended in the combination of Kaizen and Six Sigma implementation processes to reduce the first three phases of CPI as well as to improve the decision quality.

2.3 Research Gap

Though many statistical analyses and optimization approaches have been applied to improve inventory management in the oil industry, there is still a call within the industry to manage production efficiently, by eliminating overproduction, waste, and non-value added activities throughout the production line. Several studies have presented the hybrid implementation of the Kanban and CONWIP systems in different manufacturing settings. Ref. [11] applied the Kanban-CONWIP system in an environment where manual labor was intensive and back order was intolerable. The product flow time was decreased from 30 to 23 days, an improvement of 7 days (23%). Ref. [12] implemented the hybrid system in a manufacturer of electromechanical products. As a result, the on-time delivery rate was increased by 58% over 2 years, and the inventory turnover rate was increased from 3.2 to 3.6 within 3 years. Due to the successful implementation of the Kanban and CONWIP methods in other manufacturing industries, the two systems should also be able to lower inventory and lead time in the oil industry. Kanban is excellent for flexibility, while CONWIP is known for handling inconsistent lead times within the production line. To our knowledge, this research is the first one to apply Kanban and CONWIP methods to address the inventory problems in the oil industry.

3. Methodology

Our study uses a hybrid of Kanban and CONWIP Replenishment Pull Systems to reduce the WIP of finished goods in a refinery. To better understand the current production process, the research team in this study visited an oil manufacturing facility to develop a Value Stream Map (VSM), which is used to document, analyze and improve the flow of materials required to produce a product for a customer. The VSM exercise involved the university researchers, the production workers, and the process supervisors. Collectively, we were able to develop a current state VSM and identify the areas where non-value added work was most prevalent. Figure 1 illustrates the VSM for the Oil Manufacturing Facility.

After analyzing the VSM, the recommendation was to use the CONWIP approach because the signal cards were line specific, rather than part number specific, and it limited the WIP in the same manner as the Kanban cards. Next, we collected data on 142 SKU's with seventeen months' data for each SKU, and used Minitab to calculate the Mean, SE Mean, StDev, Minimum, Q1, Median, Q3, and Maximum values. After the Minitab calculations were completed, we derived the statistics below in Table 1 for each individual SKU. The Coefficient Variance for the SKU used in table 1, is 0.53, and therefore based on the variability ranges it falls in the low variability category. Thus, this indicates that the total process value added time for this particular SKU has a low variability from one period to the next. The Work in Progress Parameter is in liters and the Resizing Frequency is quarterly.

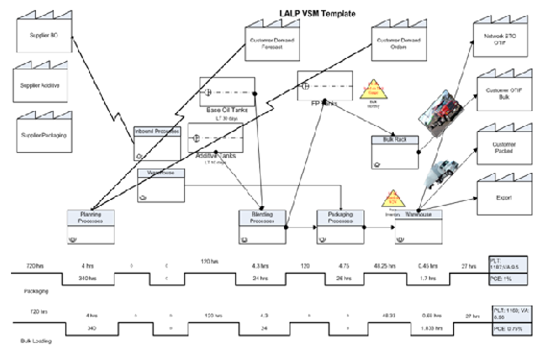

Figure 1. Current State VSM for the Oil Manufacturing Facility

Table 1. CONWIP Calculation

CV (Coef. of Varian.)	0.531396208				
Total Process Value Add Time		WIP Control Parameter		Resizing Frequency	
Low Variability	CV <0.75	Liters	X	Quarterly	X
Medium Variability	0.75< CV <=1.33	Eq. Units		Monthly	
High Variability	CV > 1.33	Time		Weekly	

4. Case Study

4.1 Current Production System

The data used for this research were derived from a lubricant plant of one of the leading Gas and Oil Companies in the United States. The challenges in the plant were in the key process functions, e.g., Bulk/Pack raw material receipt, Blending, Packaging, and General Administration and Flush, based on previous analysis. The conditions at the plant indicated many issues including, high safety stock levels, long lead times, low overall equipment effectiveness (OEE), high maintenance cost, repetitive tests in the laboratory, lack of floor utilization and optimization in the warehouse, and production planning issues. The current VSM showed that the three key focus areas were, production planning (reworking production schedule), OEE/Equipment performance, and work instruction/ standard operating procedures (WI/SOP) Alignment. Figure 2 illustrates the Pareto developed and the different issues by category identified during the VSM exercise.

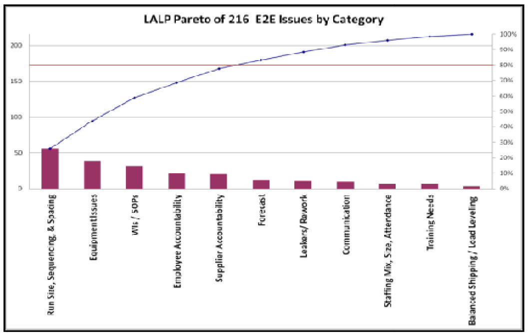

Figure 2. Pareto of 216 Issues Identified during the VSM/Kaizen Development

4.2 Data Collection

Three plant visits were made to the lubricant facilities, to learn of the current manufacturing process and to understand from start to finish how products were processed and provided to customers all through the supply chain. Data were collected in each stage of the supply chain, in regards to how much time each step of the process took. This showed the current cycle time of the production line and the opportunity for improvement in the supply chain. Data were collected through the plants' Sales and Operations Planning software, and the data collection period was approximately six months. After which, the data were analyzed using the Minitab statistical software and Microsoft Excel.

4.2.1 *Type of Data Collected*

The description of the data collected has been coded due to privacy stipulations, to conceal the identity of the company used for the case study, as well as the names of the products in their product line. We decided to use dummy variable names for the products as opposed to using the actual product names. Coding of the product description does not in any way distort the case study results. The Stock Keeping Unit (SKU) is the product identification code utilized by the manufacturing facility in this research study. These are machine readable bar codes that help track the products for inventory. The future Average on Hand (AOH) was generated from the statistical analysis done in Microsoft Excel and Minitab using the data collected. The Wall-to-Wall average was calculated based on the wall-to-wall amounts indicated in the Sales and Operations Planning software over a three-year period. The Wall-to-Wall indicates the complete inventory of each product in the warehouse. The difference between the Wall-to-Wall average and the AOH was calculated by subtracting the future AOH from the Wall-to-Wall average. This can represent the number of inventory units that each SKU can be reduced by. The cost savings was calculated by multiplying, the difference between AOH and Wall-to-Wall average, by the cost per liter, to show potential savings.

4.3 Results and Discussion

Below is a snapshot of the total finished goods savings in the amount of $3,111,349, from 142 products. Not all products are represented in this table, and the intent of the sample is to show the final cost savings results obtained from this study.

Table 2. Summary of Savings for SKU Finished Goods

DESCRIPTION	SKU	FUTURE AOH	WALL TO WALL AVERAGE	DIFFERENCE BETWEEN AOH AND WALL TO WALL	COST PER LITER	COST SAVINGS
Product 115	SKU35470	2061.140719	10360.01813	8298.877411	1.15	9543.71
Product 116	SKU36541	539.0245007	11577.84188	11038.81738	1.79	19759.48
Product 117	SKU36715	749.9936818	1830.99375	1081.000068	1.75	1891.75
Product 118	SKU36717	782.3008745	677.515	-104.7858745	1.76	-184.42
Product 119	SKU38052	4378.129304	21957.73125	17579.60195	1.24	21798.71
Product 120	SKU38111	253.783785	8963.353125	8709.56934	1.76	15328.84
Product 121	SKU38201	3638.413218	17813.15625	14174.74303	1.35	19135.90
Product 122	SKU38202	16929.35745	21626.54375	4697.186303	1.28	6012.40
Product 123	SKU38203	9836.282369	19700.925	9864.642631	1.29	12725.39
Product 124	SKU38211	2093.837015	3103.7	1009.862985	1.28	1292.62
Product 125	SKU38221	4869.846178	31495.93125	26626.08507	1.78	47394.43
Product 126	SKU38271	7064.810697	19431.2475	12366.4368	1.29	15952.70
Product 127	SKU38280	21323.91989	53784.85	32460.93011	1.23	39926.94
Product 128	SKU38290	4090.409343	27365.55	23275.14066	1.23	28628.42
Product 129	SKU38291	30386.28259	31647.33125	1261.048657	1.26	1588.92
Product 130	SKU38300	35195.55747	65267.59375	30072.03628	1.23	36988.60
Product 131	SKU38321	5688.144175	30384.0875	24695.94333	1.73	42723.98
Product 132	SKU38332	712.3520947	20443.73125	19731.37916	1.71	33740.66
Product 133	SKU38340	13249.8614	16057.8625	2808.001098	1.32	3706.56
Product 134	SKU38350	26080.89174	41611.34375	15530.45201	1.24	19257.76
Product 135	SKU38360	34169.40362	50340.5	16171.09638	1.22	19728.74
Product 136	SKU39811	2525.702019	4769.1	2243.397981	1.25	2804.25
Product 137	SKU40730	2702.121764	13029.8625	10327.74074	1.33	13735.90
Product 138	SKU40834	0	709.6875	-709.6875	1.86	-1320.02
Product 139	SKU40853	89.52511815	397.425	307.8998819	1.98	609.64
Product 140	SKU40856	199.808109	2838.75	2638.941891	1.96	5172.33
Product 141	SKU40865	79.46050608	420.135	340.6744939	1.93	657.50
Product 142	SKU41877	47.78232371	1703.25	1655.467676	3.29	5446.49
Total Savings						**$ 3,111,349.94**

This research also resulted in, a reduction of raw materials on hand at the lubricant plant, which amounted to $1.4 million savings. The $3.1 million finished goods savings shown in Table 2 above is as a result of the de-blended SKU's, which is further processing of the products to adjust specific physical and chemical properties to maintain specific ranges. The project assumed a linear reduction in Raw Materials inventory based on the reduction in Finished Goods inventory and applied cost values to the raw materials to derive the final savings.

5. Conclusion

This research study used the replenishment Pull Systems of Kanban and CONWIP to reduce the WIP of finished goods in a lubricant facility that was experiencing high safety stock levels, long lead times, low Overall Equipment Efficiency (OEE), high maintenance costs, etc. The first step was to conduct a current VSM exercise to frame near-term and future state opportunities to optimize cost structures and operational excellence parameters. The VSM served as a leverage for calculations and illustration, helped to build an end-to-end understanding of the value chain at the lubrication plant, and helped identify process owners across the chain, (i.e. blending, planning, logistics, filling, etc.). The second step was to conduct a Pareto analysis of the 216 issues identified during the VSM. The Pareto principle, also known as 80/20 rule, states that 20% of effort yields 80% of results. After analyzing the VSM, the recommendation is to use the CONWIP approach, because from a push/pull perspective, the CONWIP cards limit the WIP in the same manner as the Kanban cards. An important difference from Kanban as it relates to an implementation standpoint is that the signal cards are line specific rather than part number specific. The CONWIP calculation demonstrated the variability of each SKU, ranging from Low, Medium, and High Variability. If the coefficient of variance is below 0.75, it falls into the low variability range; if it is within 0.75 and 1.33, it falls in the medium variability range; and if it is higher than 1.33, it falls in the high variability range. The WIP control parameter used was in liters and the resizing frequency was quarterly. We were able to calculate what the Future AOH should be on each product, and we compared them to the current AOH. The difference (reduced AOH) in each inventory AOH, multiplied by the cost per liter, is the cost savings per product. This amounts to the total savings of $3.1 million. And the reduction of raw materials on hand at the lubricant plant amounts to $1.4 million savings. Therefore, through this research initiative a total of $4.5 million dollars of costs savings were obtained for this lubricants facility. The future work for this study involves applying the techniques and statistical models used in this research to other lubricant plants and other Oil and Gas companies to drive the same cost saving results and more.

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